A Novel Simulation Methodology Merging Source-Sink Dynamics and Landscape Connectivity

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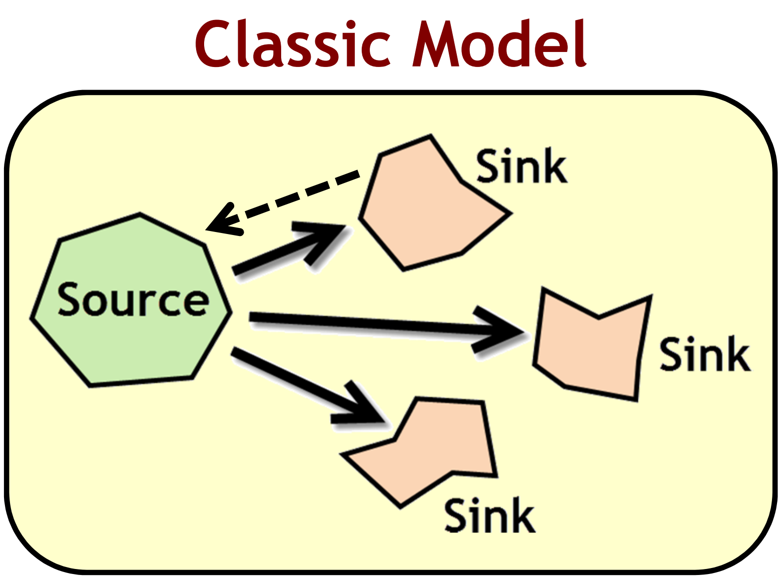
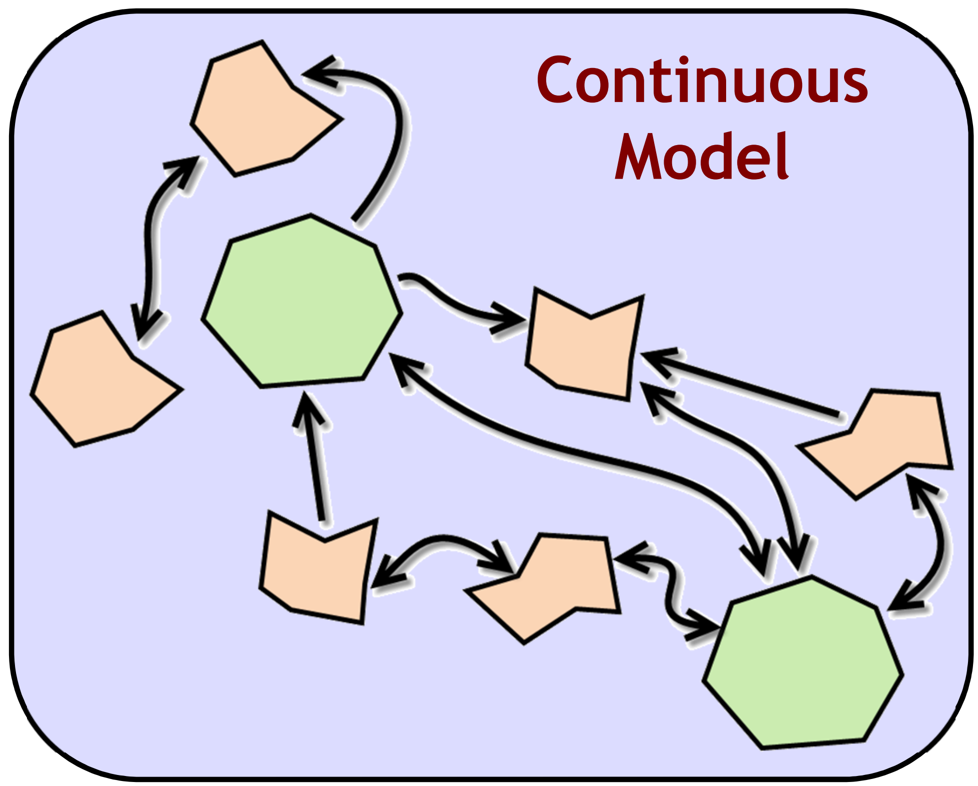
Introduction

- A critical element of conservation planning involves assessing the importance of various habitat units for regional population viability.
- Graph theory, circuit theory, and network flow provide such insights because they indicate how parts of a landscape function together as networks.
- The methodology we describe complements these tools. Importantly, it does so without constraining the realism of the underlying population models.

Sources, Sinks and Connectivity

- Classic model defines sources to be locations producing excess individuals that subsequently travel to sinks.
- In the continuous model, source and sink regions emerge from multiple complex fluxes mediated by connectivity.





Overview of Our Methodology

1) Develop a simulation model of the system. May be as simple or complex as desired.

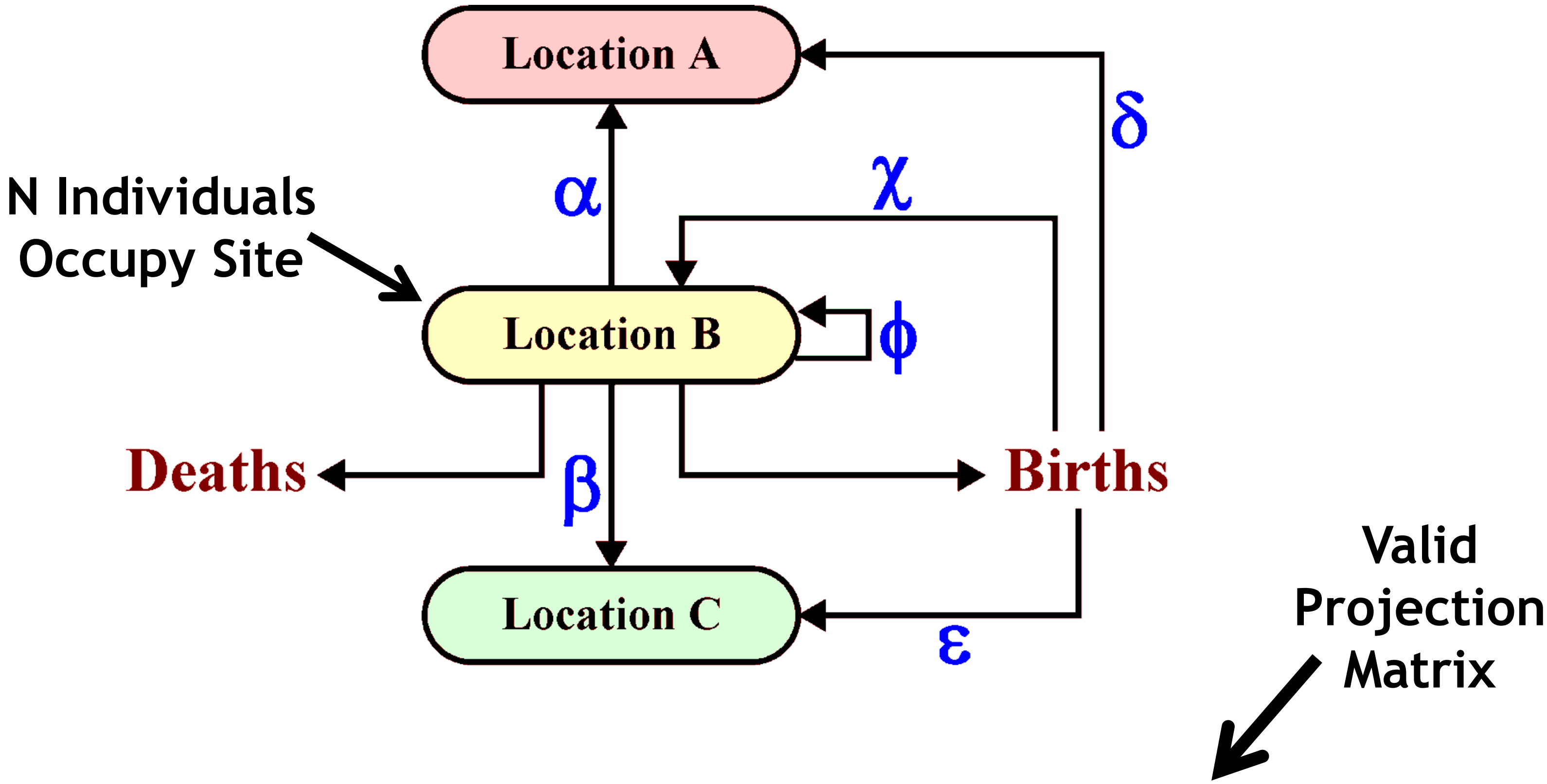
2) Construct one or more spatial sampling regimes. Run the model while tracking all movement between the sampling locations.

3) Generate matrices of movement counts and rates from the simulation model output.

4) Use the matrices to quantify source-sink structure, Net Flux, and other descriptions of the species-landscape interactions.

Matrix Construction Process

Built Into the HexSim Model…



Counts		From		
		A	B	C
To	A	...	$\Sigma\,(\alpha + \delta)$	...
	B	...	$\Sigma\,(\phi + \chi)$	...
	C	...	$\Sigma\,(\beta + \varepsilon)$	...

Rates		From		
		A	B	C
To	A	...	$\Sigma\,(\alpha + \delta) \,/\, \Sigma\,N$	...
	B	...	$\Sigma\,(\phi + \chi) \,/\, \Sigma\,N$	...
	C	...	$\Sigma\,(\beta + \varepsilon) \,/\, \Sigma\,N$	...

Three Key Metrics

COUNT-BASED MATRIX

8812	321	13211	1034
172851	0	52518	442
1689482	0	2248	0
0	11389	1580	12618

RATE-BASED MATRIX

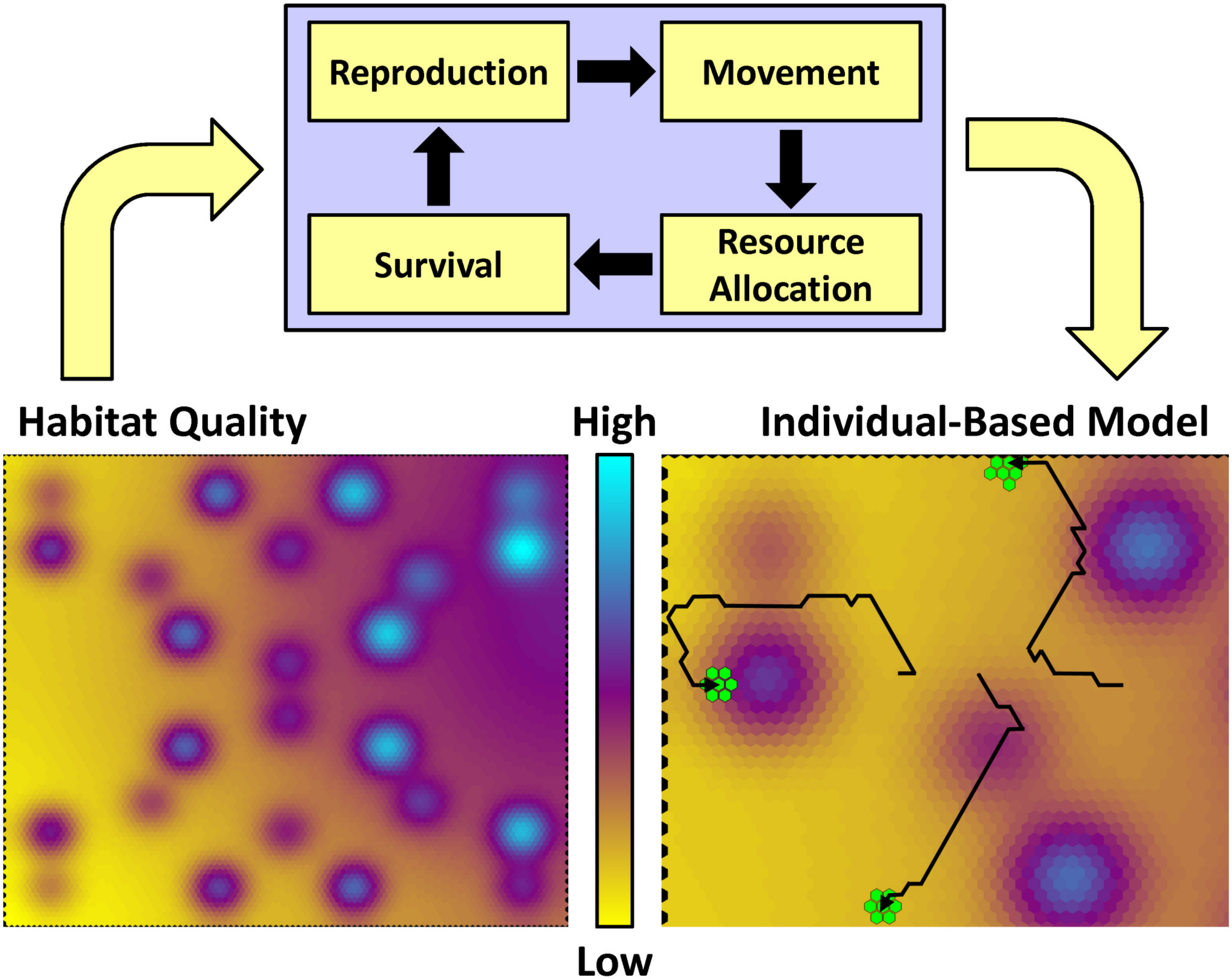
0.0048	0.0077	0.0111	0.0035
0.0943	0.0000	0.0439	0.0015
0.9216	0.0000	0.0019	0.0000
0.0000	0.2737	0.0013	0.0427

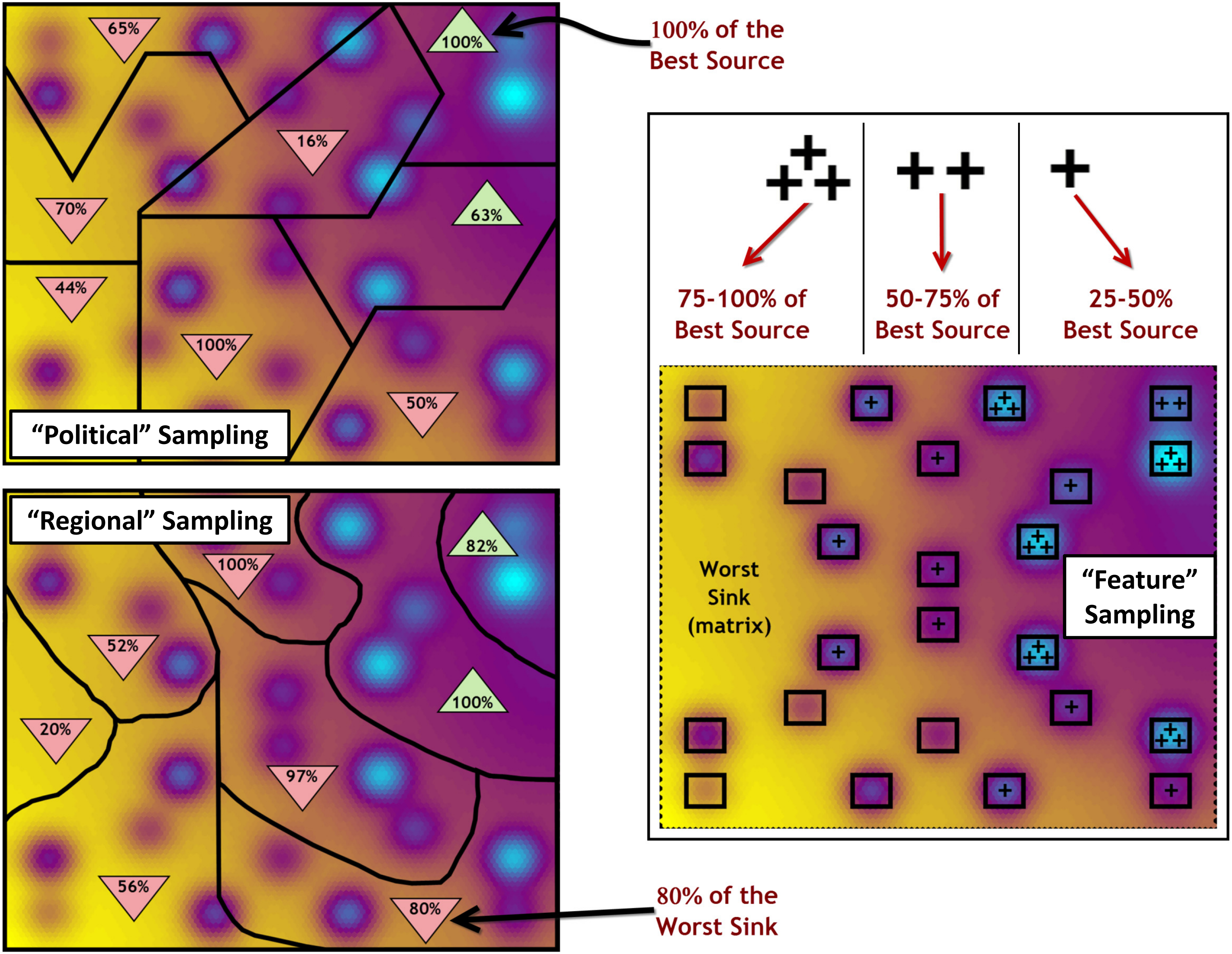
1. Source-Sink Value(i) = Row Sum_i – Column Sum_i

2. Net Flux(k, i) = $\mathrm{Matrix}_{i,k} - \mathrm{Matrix}_{k,i}$

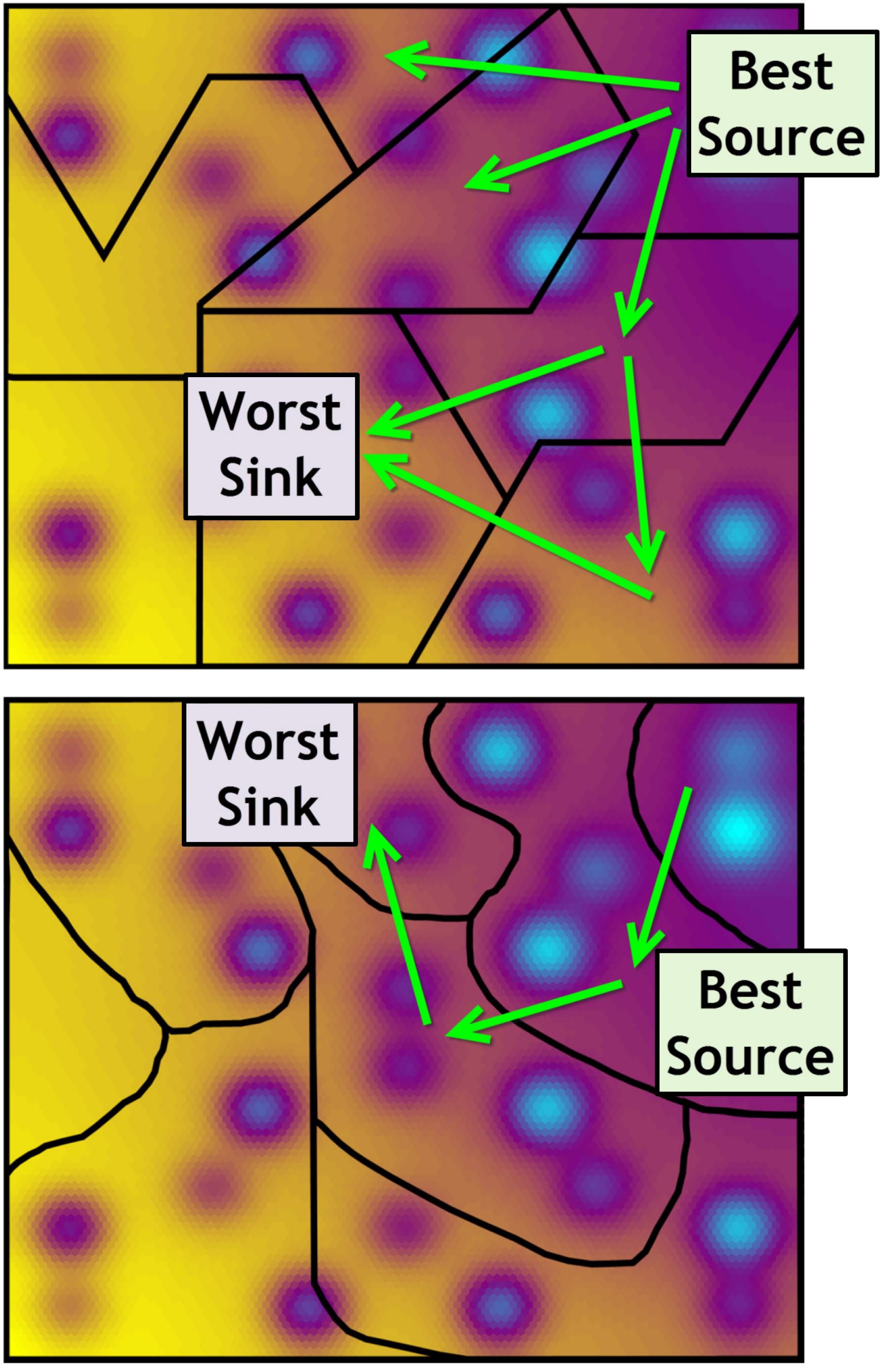
3. $\Delta\lambda = [\lambda(\text{modified}) - \lambda(\text{original})] / \lambda(\text{original})$

A Simple Fabricated Example



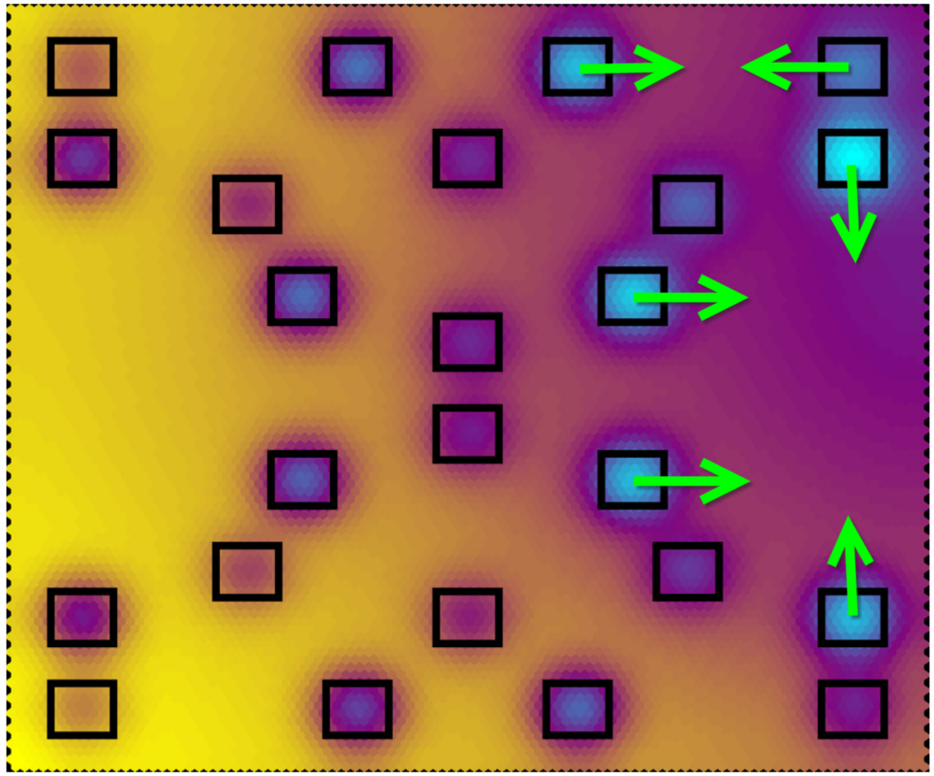


65%
100%
16%
70%
63%
44%
100%
50%
"Political" Sampling
100% of the Best Source
"Regional" Sampling
82%
100%
52%
20%
100%
97%
56%
80%
80% of the Worst Sink
75-100% of Best Source
50-75% of Best Source
25-50% Best Source
Worst Sink (matrix)
"Feature" Sampling



Net Flux

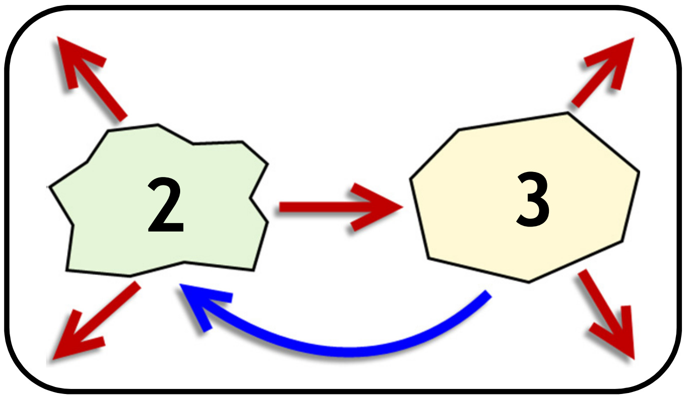
Arrows show values at least 50% of the Maximum



In the discontinuous sampling regime, all significant Net Fluxes were into the matrix...

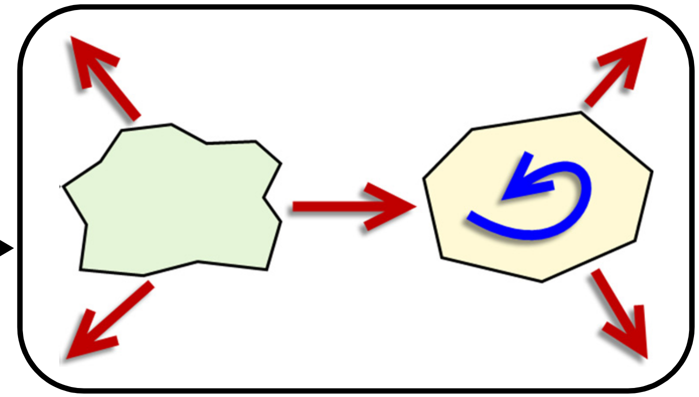
The Δλ Metric

$$\Delta\lambda = [\lambda\,(\text{modified}) - \lambda(\text{original})]\ /\ \lambda(\text{original})$$



← Original

Modified →



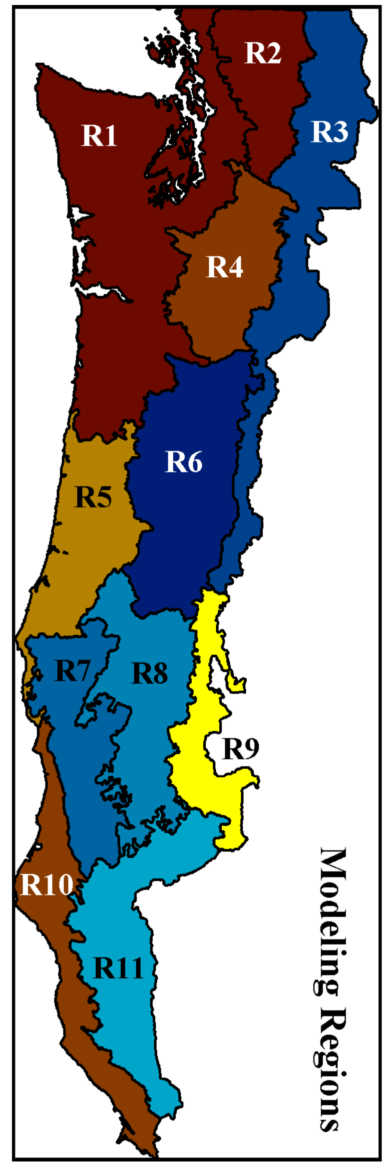
Δλ Computed from the original projection matrix

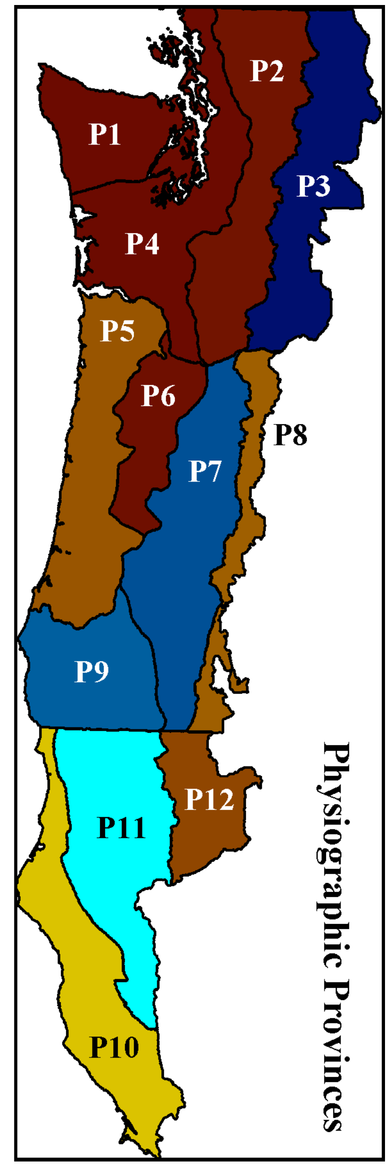
Add the rate corresponding to the blue flux to the diagonal term. Then set it to zero.

	FROM			
TO	0.0048	0.0077	0.0111	0.0035
	0.0943	0.0000	$\boxed{0.0439}$	0.0015
	0.9216	0.0000	0.0019	0.0000
	0.0000	0.2737	0.0013	0.0427

Northern Spotted Owl

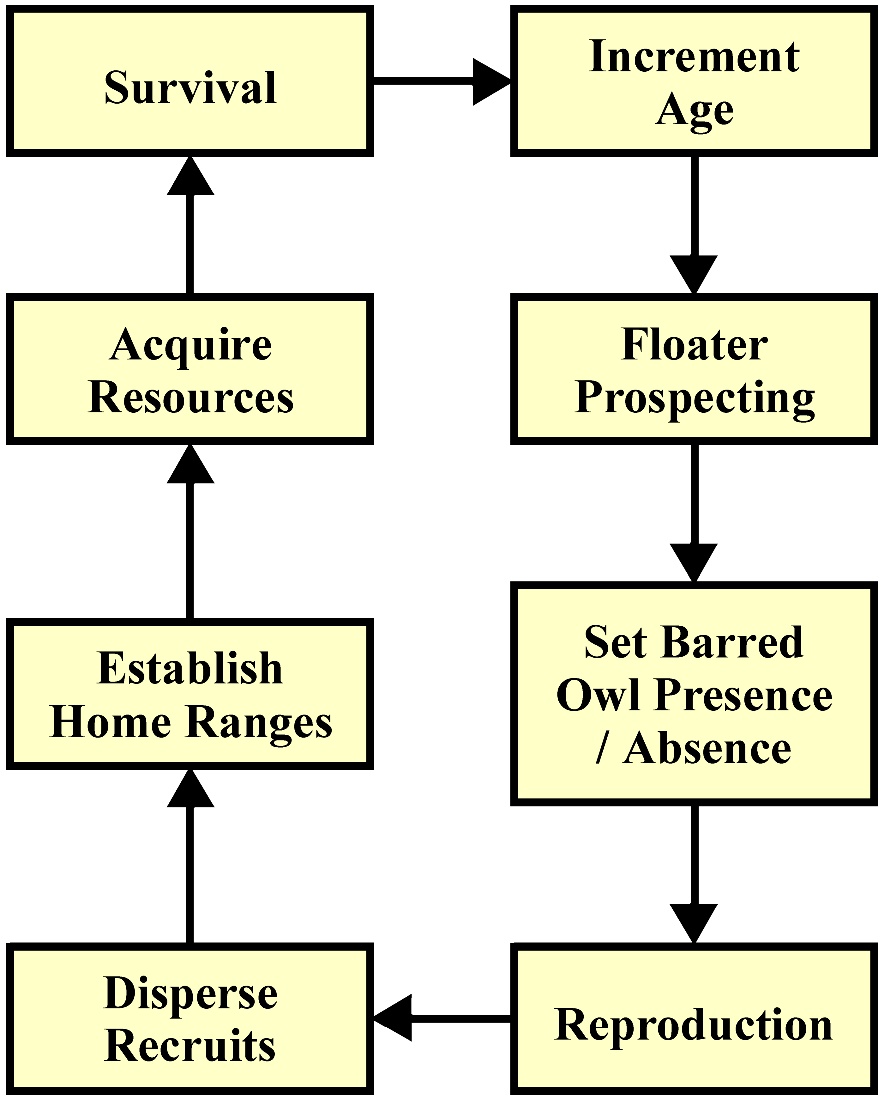
Model Constructed as part of the US FWS 2012 Recovery Plan



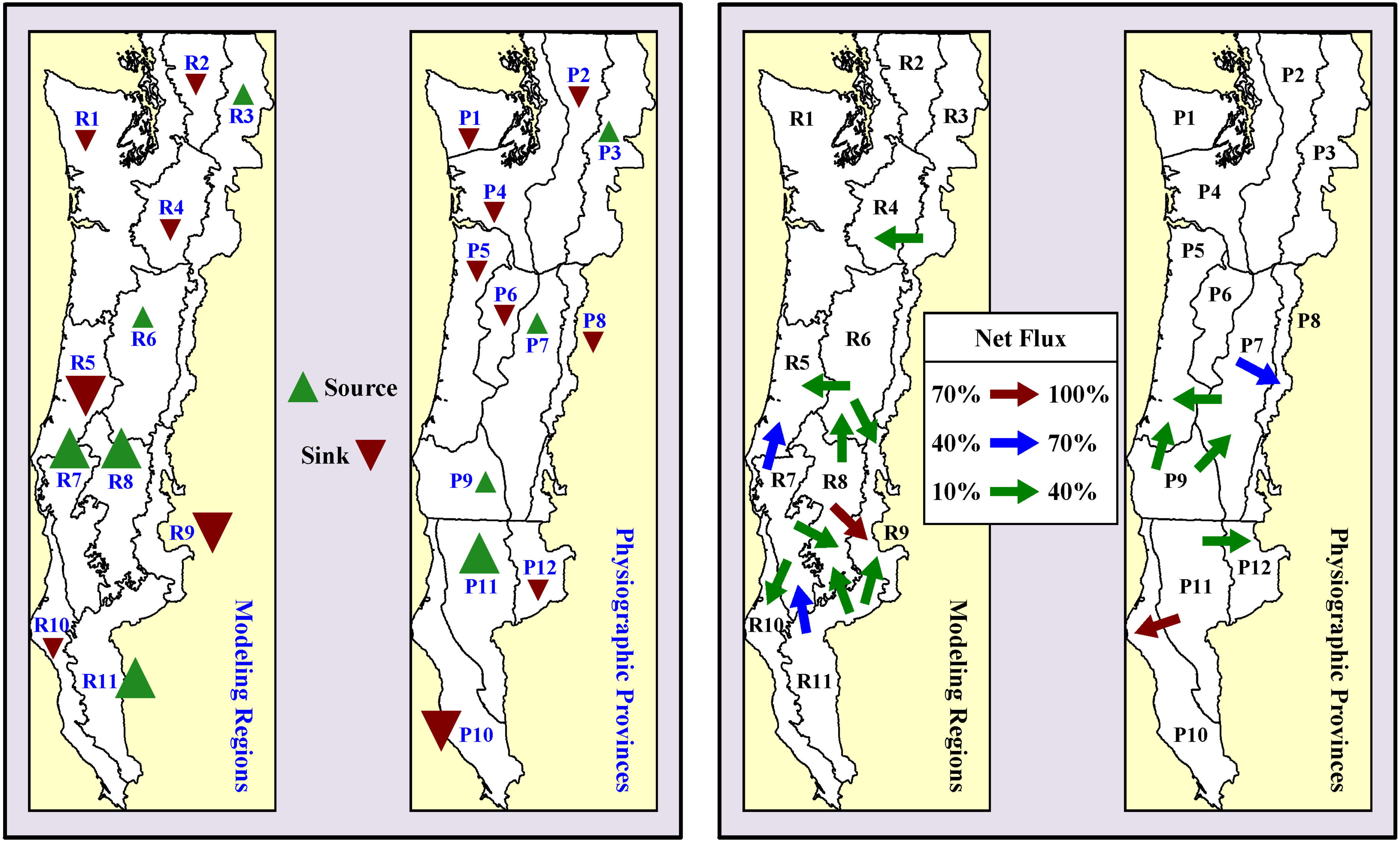


The Simulated NSO Life Cycle

(Moderately Complex HexSim Model)

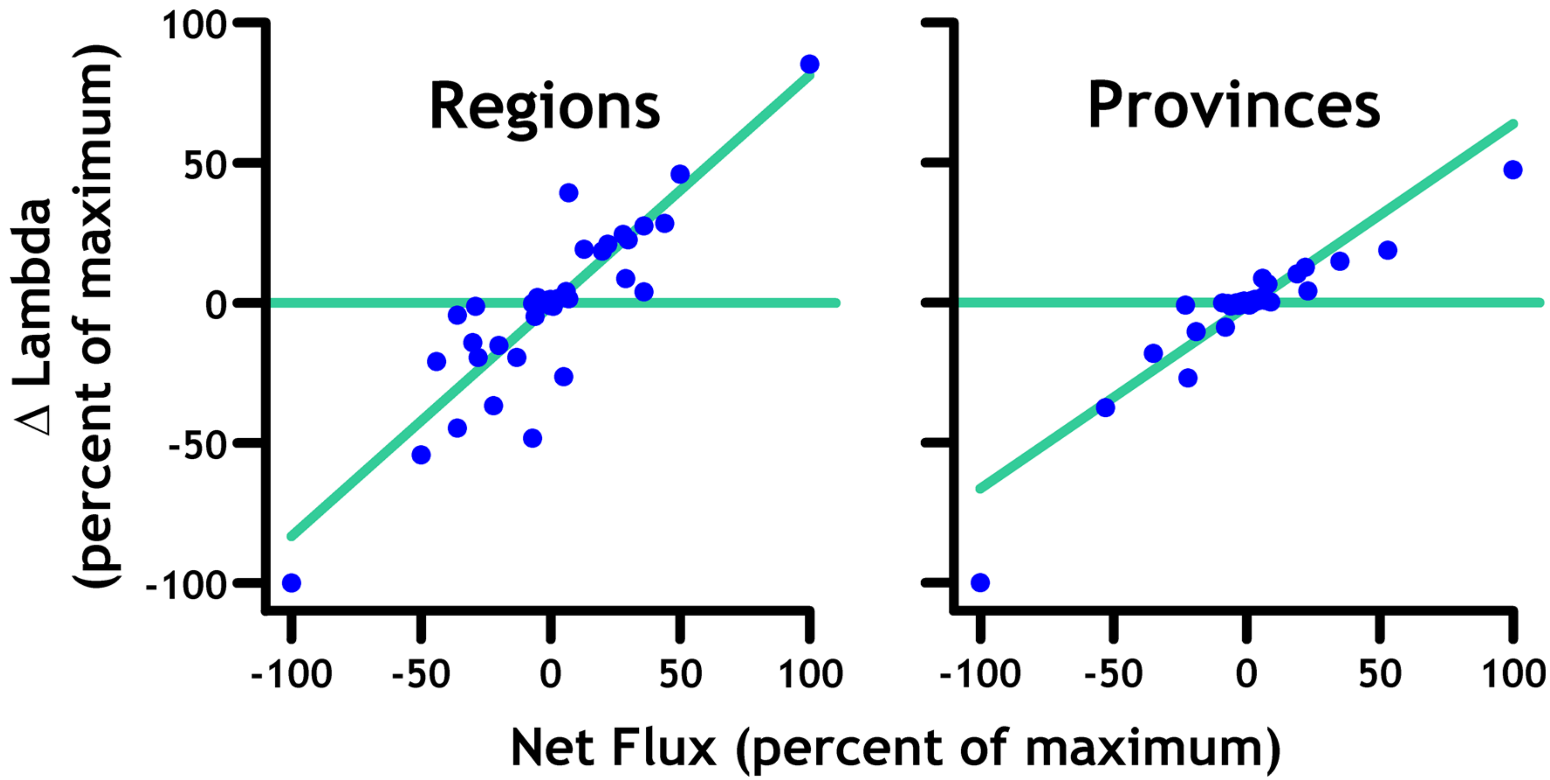


Source-Sink Structure + Net Flux



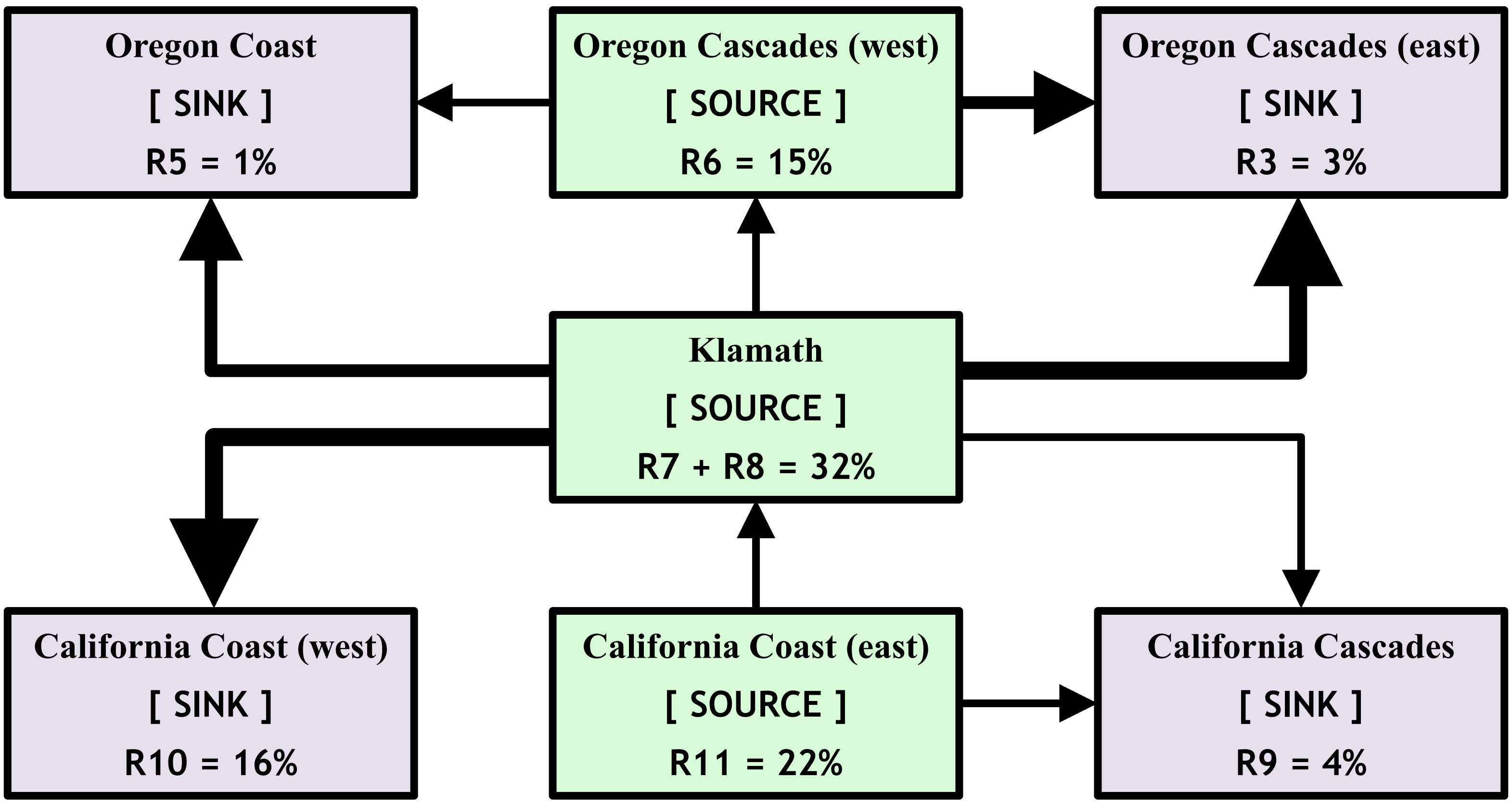
Net Flux Predicts Δλ

79% (Regions) and 85% (Provinces) of the Variation in Δλ was Explained by Net Flux



NSO Spatial Dependencies

Thicker Lines Indicate Larger Net Fluxes



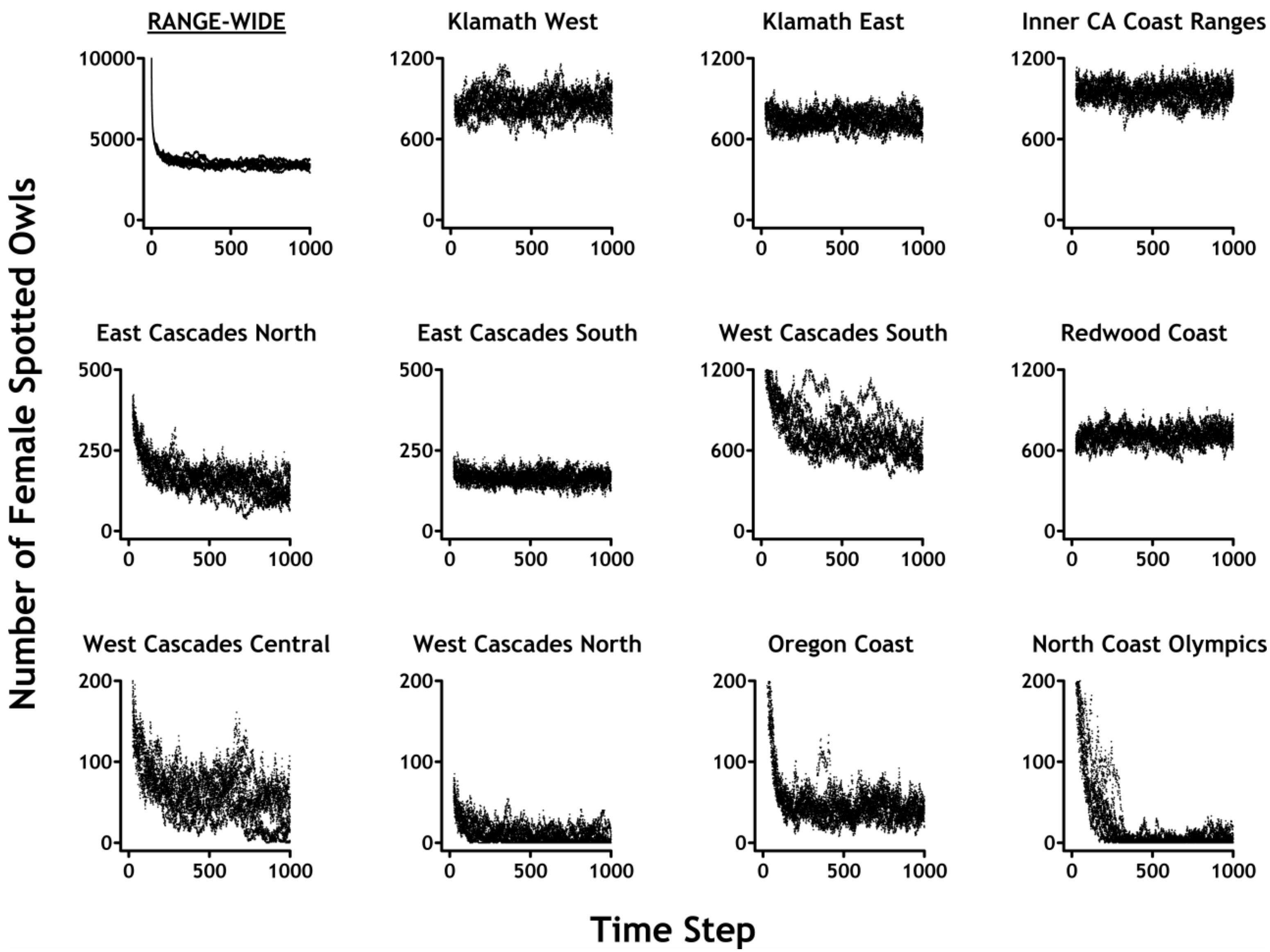
Conclusions

- Good correlations with $\Delta\lambda$ demonstrate that Net Flux has population-level significance.
- Source-sink value and Net Flux can be used together to identify spatial dependencies important for population persistence.
- This conceptually simple method imposes no constraints on model detail or realism.
- Future studies will better illustrate the practical value of the approach.

www.hexsim.net

Model Validation

The Study Benefited from Abundant Data



Results - Source / Sink

Modeling Regions	Map Index	Type	Percent of Worst Sink or Best Source
East Cascades South	R9	Sink	100
Oregon Coast	R5	Sink	50.7
Redwood Coast	R10	Sink	23.1
West Cascades Central	R4	Sink	20.5
West Cascades North	R2	Sink	3.8
North Coast Olympics	R1	Sink	3.6
West Cascades South	R6	Source	13.3
East Cascades North	R3	Source	37.5
Klamath West	R7	Source	57.0
Klamath East	R8	Source	77.2
Inner California Coast Ranges	R11	Source	100

Physiographic Province	Map Index	Type	Percent of Worst Sink Or Best Source
California Coast Range	P10	Sink	100
Oregon Eastern Cascades	P8	Sink	48.2
Oregon Coast Range	P5	Sink	42.5
California Cascades	P12	Sink	35.9
Washington Western Cascades	P2	Sink	8.4
Oregon Willamette Valley	P6	Sink	6.3
Washington Western Lowlands	P4	Sink	3.3
Washington Olympic Peninsula	P1	Sink	0.1
Washington Eastern Cascades	P3	Source	3.6
Oregon Western Cascades	P7	Source	29.2
Oregon Klamath	P9	Source	35.9
California Klamath	P11	Source	100

Results - Net Flux and $\Delta\lambda$

Starting Modeling Region	Ending Modeling Region	Net Flux	$\Delta\lambda^R$
Klamath East	East Cascades South	100% (12,786)	85% (-100%)
Klamath West	Oregon Coast	50% (6333)	46% (-54%)
Inner California Coast Ranges	Klamath West	44% (5675)	28% (-21%)
Klamath West	Redwood Coast	36% (4627)	4% (-5%)
Klamath East	West Cascades South	36% (4603)	27% (-45%)
Inner California Coast Ranges	East Cascades South	30% (3882)	22% (-14%)
West Cascades South	Oregon Coast	29% (3664)	9% (-1%)
West Cascades South	East Cascades South	28% (3556)	24% (-20%)
East Cascades North	West Cascades Central	22% (2790)	21% (-37%)
Inner California Coast Ranges	Klamath East	20% (2523)	18% (-15%)
Klamath West	Klamath East	13% (1623)	19% (-20%)

Starting Physiographic Province	Ending Physiographic Province	Net Flux	$\Delta\lambda^R$
California Klamath	California Coast Range	100% (15,029)	47% (-100%)
Oregon Western Cascades	Oregon Eastern Cascades	53% (7954)	19% (-38%)
Oregon Klamath	Oregon Western Cascades	35% (5255)	15% (-18%)
Oregon Western Cascades	Oregon Coast Range	23% (3447)	4% (-1%)
California Klamath	California Cascades	22% (3343)	13% (-27%)
Oregon Klamath	Oregon Coast Range	19% (2891)	10% (-10%)